LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

BRITISH MUSEUM (NATURAL HISTORY)

THE

JOHN MURRAY EXPEDITION

1933–34

SCIENTIFIC REPORTS

VOLUME I. No. 3

AN ACCOUNT OF ADDU ATOLL

BY

R. B. SEYMOUR SEWELL, C.I.E., Sc.D., F.R.S.

(Lieut.-Colonel, I.M.S. (ret.).)

WITH EIGHT PLATES AND ONE TEXT-FIGURE

LONDON:
PRINTED BY ORDER OF THE TRUSTEES OF THE BRITISH MUSEUM
SOLD BY
B. Quaritch, Ltd., 11 Grafton Street, New Bond Street, London, W.1; Dulau & Co., Ltd., 2 Stafford Street, London, W.1; Oxford University Press, Warwick Square, London, E.C.4
AND AT
The British Museum (Natural History), Cromwell Road, London, S.W.7
1936

[*All rights reserved*]

Price Five Shillings

[*Issued 27th June, 1936*]

DESIGNED AND
PRINTED
BY
ADLARD & SON, LTD.
21, HART STREET, W.C.
AT
BARTHOLOMEW PRESS
DORKING

Made and printed in Great Britain.

LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

AN ACCOUNT OF ADDU ATOLL

BY

R. B. SEYMOUR SEWELL, C.I.E., Sc.D., F.R.S.
(Lieut.-Colonel, I.M.S. (ret.).)

WITH EIGHT PLATES AND ONE TEXT-FIGURE

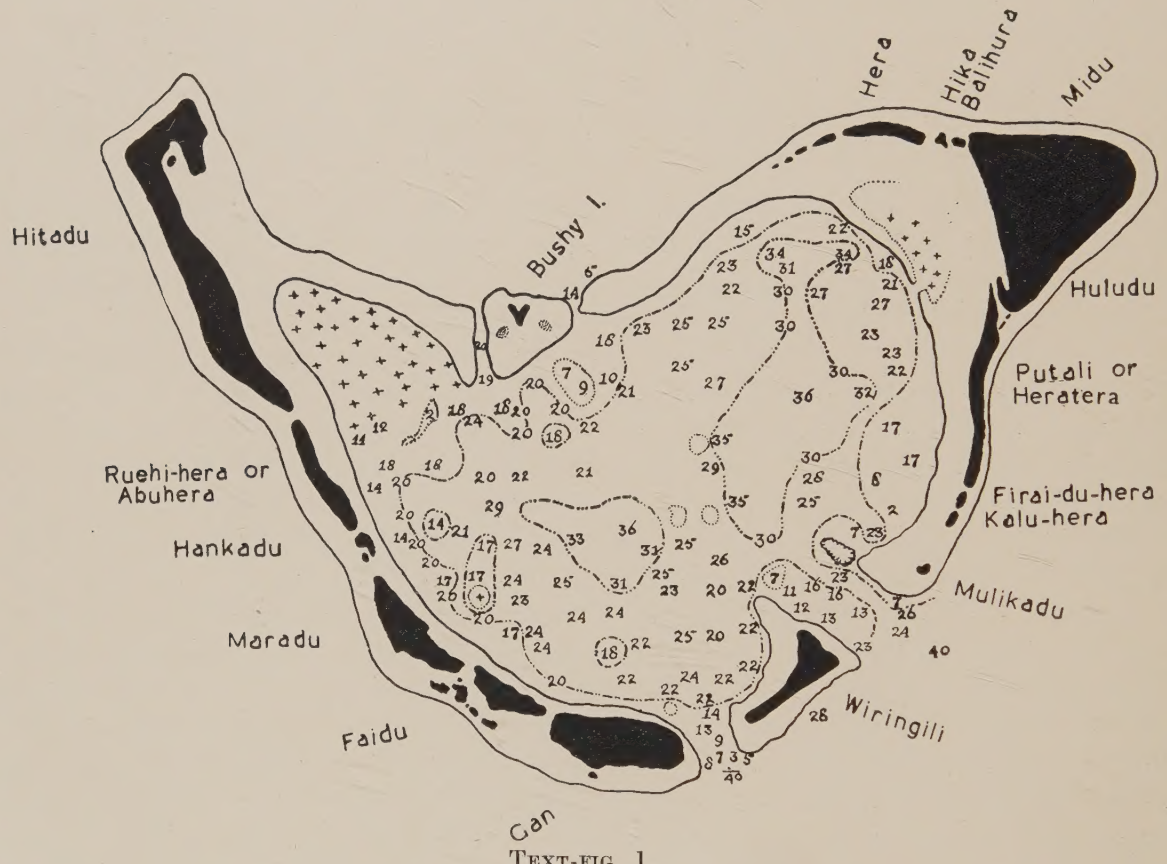
Addu Atoll is the most southerly atoll of the Maldive Archipelago, and is situated in lat. 0° 36′ 30″ S., long. 73° 09′ 30″ E. It occupies a position at the extreme south end of the archipelago very similar to that which Minikoi occupies at the north ; both arise as completely isolated atolls from a depth of some 900–1000 fathoms.

Addu atoll was first surveyed by Moresby in 1836, and since then it has been visited by Stanley Gardiner and Forster Cooper in 1900, and by Agassiz in 1902. Both Stanley Gardiner and Agassiz have given more or less detailed accounts of the atoll and have compared their results with Moresby's original chart ; it may therefore be thought that any further account of the atoll is unnecessary, but my excuse is that after a lapse of some thirty years a further re-study of the same area has a special interest, in that it enables one to note the changes that have taken place in the meantime.

Agassiz (1903, p. 145) has described the atoll as being triangular in shape ; it is, however, more nearly correct to call it crescentic, and Agassiz himself called attention to the two horns that jut out at the north-east and north-west ends of the atoll. The two borders of the crescent exhibit marked differences. At the two horns and scattered along the southern border are numerous islands, three of which, namely Midu-Huludu at the extreme eastern horn, Hitadu at the western horn, and Gan, just where the curved rim reaches its most southerly point, are considerably larger than the others. The concave northern border of the crescent presents a marked contrast to the southern rim, in that it is formed by an almost bare reef, on which only a few small islands and " sand-cays " are situated. Both the northern and southern rims are broken about the middle of their length, and in each case a small central portion of the reef is isolated by deep channels that connect the lagoon with the surrounding ocean.

To what extent the shape of the atoll is attributable to the configuration of the mountain peak on which the atoll is situated on the one hand, and the different rates of growth of the reef itself, under the influence of surface currents, etc., it is at present impossible to decide. The presence of the coral island Fua-Mulaku to the north-east of Addu atoll suggests that the basic mass on which the atoll is perched extends considerably towards the north-east, and in this connection it is interesting to note that Farquharson, in his account of the topography of this region (1936, p. 56), remarks that " soundings obtained by " Mabahiss " and one of the German cruisers suggest that the southern atolls

of Haddumatti, Suvadiva, Addu and the Island of Fua-Mulaku are also connected at depths less than 700 fathoms. These atolls may also be connected with the central mass below the 1000 fathom line. This southern mass differs from the others (to the north) in that its eastern slopes fall to depths as great as those on its western side". To the eastern and north-eastern side of Addu atoll the seaward slope is very gradual, the 50-fathom contour not being reached till some three-quarters of a mile from the reef edge; at this point there is a sharp increase in the angle of the slope down to about 200 fathoms, and then comes a more gradual slope down to 250 fathoms, followed again by a steep slope to nearly 400 fathoms. Beyond this, at a distance of about $1\frac{1}{3}$ miles from the reef edge,



TEXT-FIG. 1.

the character of the slope changes and now shows a tendency to become convex, falling slowly to 750 fathoms, which is reached at about $2\frac{1}{3}$ miles from the reef. Further seaward the slope again becomes very gradual, so that between $2\frac{1}{2}$ and $3\frac{1}{2}$ miles out the depth increases by only some 100 fathoms; soon after the $3\frac{1}{2}$-mile distance is reached the bottom again drops, and the 1000-fathom level is reached in another $\frac{3}{4}$ mile (Chart 5). According to the contours drawn by Farquharson, there are indications of a Y-shaped ridge running out from the atoll in an easterly direction, the northern bifurcation of the Y turning in the direction of Fua-Mulaku. It would thus seem probable that there is a natural tendency for the submarine contours to extend towards the east and north-east, and this might account, at any rate in part, for the existence of the north-eastern horn of the atoll.

It is generally admitted that the usual effect of an ocean current, bringing with it

increased food-supplies for the coral polyps and their symbionts, will be to promote an increased rate of growth and a consequent extension of the reef in the direction from which the current is flowing ; but at the same time one must not forget the fact, to which Darwin drew attention as long ago as 1842, that reefs exhibit a tendency to extend in the direction of the current that flows along them. Two distinct processes are in all probability at work, namely (1) the supply of nutriment leading to more active growth and hence to an extension of the reef, and (2) the distribution of the fragments broken off a reef, and the gradual building up of a talus slope on which the reef can extend. In the region of the Maldives the surface currents exhibit great changes at different seasons of the year and in different parts of the Archipelago. Agassiz (1903, p. 145) has drawn a comparison between Minikoi and Addu atolls, and points out that the " climatic conditions under which they are placed are quite different. Minikoi is in the region of the north-east and south-west monsoons, while Addu is in the equatorial region of variable southerly and westerly winds, with rain squalls prevailing ". The latter part of this statement hardly agrees with my experience. During January and February and the first half of March the wind is usually from the north-east, and blows with a force of 2–3 Beaufort scale ; Stanley Gardiner (1903, pp. 20–21) found that the north-east monsoon was felt in Addu from " January to March, but the wind is here very irregular, veering at any time six points on either side of north-east ". During the transitional period between the north-east and south-west monsoons the winds experienced are very variable, but on the whole exhibit a tendency to blow from the north-west. Forster Cooper (*vide* Stanley Gardiner, 1903, p. 26) was in this region in the months of March and April, 1900, and in his notes he states, " in my journey through the atolls of South Mále, Felidu, Mulaku, Kolumadulu and Haddummati I experienced only north-westerly winds with the exception of an easterly gale, lasting three days, while I was in the south of Felidu atoll ". In the latter part of March and early April, 1934, we found that in this area the wind was variable, but in the main blew from the north-west or west-north-west with a force 3, rising at times to force 4 Beaufort scale. It is probable that the strength and persistence of north-westerly winds varies considerably in different years and at different seasons of the year. The 'West Coast of India Pilot' (1919, p. 348) states that in Equatorial Channel, which separates Addu and Suvadiva atolls, " in September the north-west monsoon (which prevails for nearly all the first half of the year from the Equator to Chagos Archipelago, commences with about a fortnight's hard squalls and fresh gales from the West to W.N.W.", and this must also be felt to some and possibly to a considerable extent at Addu.

It is also during this season of the year, or during the corresponding change from the south-west to the north-east monsoons in September–October, that cyclones are most likely to arise in the Laccadive Sea ; as Oldham (1895, p. 12) has pointed out, " Hurricanes (cyclones) are rare at the Laccadives, but between these islands and the coast of India and to the south-eastward over the southern end of the Indian Peninsula hurricanes are comparatively frequent. Their course is to the W.N.W. or north-westward, passing up between the Laccadives and the Malabar coast ". Such storms will give rise to gales and heavy seas from the north-west or west in Addu atoll ; and it seems probable that these north-westerly winds are responsible for several features both in the rim of the atoll and in some of the islands on the reef-platform. As Murray (1913, p. 69) remarks, " in the Indian Ocean a comparatively low surface temperature prevails over the north-western portion of the Arabian Sea, brought about by the prevailing north-westerly

winds driving the warm surface water to the south-eastward and thus by upwelling off Cape Gardafui bringing the colder waters of the lower depths nearer to the surface ". This effect of the north-westerly winds will be to produce a surface current that will impinge on Addu atoll at the north-west corner and, by bringing increased food-supplies, should be favourable to the growth of coral and the consequent extension of the reef at this point. Similarly the effect of the north-east monsoon wind, combined with the north Equatorial Current, would be favourable to growth and extension of the reef in that direction. Stanley Gardiner (1903, p. 416) concludes from the observations taken by himself and Forster Cooper that " the chief points to seaward (in the contour of the atoll) are all more emphasized and prominent at the present day than shown in his (Moresby's) chart ", and again (*loc. cit.*, p. 151) he remarks that " the seaward edge of the reef, particularly round the semicircle to the south and at the two horns (north-east and north-west), has grown considerably outwards ". A comparison of the charts given by Moresby and Stanley Gardiner with the condition at the present day would appear to indicate that there has been a very great outgrowth at the two horns, and especially to the north-west. My own observations lead me to conclude that the north-western horn projects out from the main mass of the atoll even further than Stanley Gardiner has shown it, and I have indicated this in the chart. If we accept the accuracy of the previous charts one must conclude that the north-west horn has grown out approximately 1 mile between 1836 and 1900, and a further $\frac{1}{2}$ mile between 1900 and 1934, a rate of extension of 26·4 yards a year, or 2·2 yards a month ! One hesitates to bring an accusation of inaccuracy against a trained surveyor, such as Moresby, though when one considers the conditions under which his survey was made one is surprised that he attained results as accurate as he did ; but a comparison of the land contours of the island on the north-west horn, as shown in the various charts, clearly reveals such a degree of similarity that one is forced to conclude that there has been little or no change in this part of the atoll, and that the apparent outgrowth of the north-west corner is due to faulty charting ; but there seems to be no room for doubt that the north-east has extended outwards to some, and possibly to a considerable extent.

The other ocean current that might influence the rate of growth of the reef and, therefore, the shape of the atoll is that of the south-west monsoon. Situated as this atoll is to the south of the equator, it is out of the line of the full force of the south-west wind at this season of the year and, indeed, the ' West Coast of India Pilot ' states that " Addu atoll is almost beyond the influence of the south-west monsoon ". Stanley Gardiner (1903, p. 21) also states that in this atoll the south-west monsoon is not felt. This, in my opinion, is an over-statement ; there is a definite effect produced by this monsoon, though to a less extent than further to the north, and furthermore, the main direction of the wind at this season is from the west to west-south-west rather than strictly from the south-west, and this is in agreement with Stanley Gardiner's own experience, for he (1903, p. 21) records that he experienced " in the channels between Addu and Suvadiva and between the latter and Haddumati heavy gales from the west ".

Such a wind will produce a surface current that at first one might consider would be favourable to the growth of coral, but the onset of this westerly wind is often accompanied by heavy rain and a fall in the temperature of the water, so that the possibly beneficial effect of an increased food-supply may to some extent be counterbalanced, and there certainly seems to be little, if any, tendency for the reef to grow out towards the

south-west. Owing to the configuration of the atoll a south-westerly moving current, striking against the north-east corner, will tend to be diverted, part flowing southwards along the east face of the atoll and part passing along the north face, and so finally being diverted towards the north-west. Similarly a north-easterly moving current, impinging on the south-west side of the atoll, will be diverted towards the north ; and it is possible that this movement of the water during the two monsoons has had some influence in moulding the projection of the north-west horn.

I have already mentioned that both north and south sides of the atoll rim are interrupted by channels. The position of these openings is interesting ; it is generally stated and accepted that the channels out of the lagoons into the open sea are for the most part to be found on the lee-side of an atoll, the view being that they are kept open by the outflowing current of water that has been spilled over the windward reef by the breaking waves. In Addu atoll, owing to the alternating seasons, the lee-side will be the south-west side from November to January or February, during the period of the north-east monsoon, and the north-east and east sides will be the lee side during the period of the south-west monsoon from May to August. The effect of this alternation of the direction of the wind will be that these seasons tend to neutralize each other, so far as their effect on maintaining channels through the reef is concerned. In March, and again in September and October, the prevailing wind is from the north-west, and, moreover, it may blow from this quarter with considerable force, whereas it but rarely blows from the south-east. The effect of a strong north-westerly wind will be to pile up the water in the concavity of the northern reef, through the channels of which it will flow into the lagoon, and from thence it will in turn escape by the channels through the southern reef. It is interesting to note that the line passing through both sets of channels runs in a direction 30° west of north.

Of the four openings, those on the south side are the more important, as they are considerably wider than those in the northern rim. The south-western channel, between Wiringili and Gan Islands, is comparatively shallow, but the south-eastern one, between Wiringili and Mulikadu Islands, is deep, having 20 fathoms of water throughout the greater part of its length. In the neighbourhood of this latter channel the reef has grown inwards towards the centre of the lagoon for a considerable distance, thus prolonging the entrance channel, and on each side there is, in addition, a detached extension of the coral reef beyond the actual end of the lagoon reef, and separated from it by a depth of 10 fathoms or more. On the east side of the channel this detached area has grown up to the surface and is exposed at low tide : Stanley Gardiner (1903, p. 319) states that the patch to the north of the south-east passage, charted by Moresby in 1836, has become joined to the reef ; but in this he is mistaken. He figures it quite correctly as separate from the outer reef, and there was between them at the time of my visit a channel with a depth of water of over 10 fathoms. On the west side, beyond the point of the outer reef, lies the detached shoal that was discovered by Forster Cooper (*vide* Stanley Gardiner, 1903, p. 319), and beyond this again is another somewhat larger shoal that rises from 26 fathoms in the channel to 17 fathoms in the middle of the shoal.

In the channel of the south-west entrance there is no indication whatsoever of any tendency on the part of the reef to grow inwards towards the lagoon. This difference between the two openings is interesting, and is doubtless correlated with the different behaviour of the tidal currents in the two channels. During the flood tide a strong

current sets in through the south-east entrance and, simultaneously, an equally strong current sets out of the lagoon through the south-western channel ; on the ebb the current sets out from the lagoon through both channels ; thus, whereas in the eastern channel there is a reversal of the surface current with the change of the tide, in the west channel the current flows continuously out of the lagoon. The inward trend of the reef on the two sides of the deep eastern channel is probably correlated with this inward current, and the action of waves sufficiently powerful to detach fragments of coral from the reef and fling them inwards—a process that is clearly shown in these channels by the heaping-up of small islands on either side of the entrance ; the talus slope thus produced would be modelled by the inflowing current into spits running inwards on either side of the entrance. On the other hand, the view that these entrance channels are kept open by the action of the outflowing current, which brings with it silt from the lagoon and thus smothers the corals that otherwise might grow in the bed of the channel, is not borne out by the conditions present in this atoll, for clearly, if this were the true cause, then the western channel, through which the current at all times sets out from the lagoon, should be the deeper of the two, whereas, as we have just seen, the exact opposite is the case.

The two northern channels are narrower than the southern ones, and here again we find that one is rather deeper than the other. The western channel has a depth of 20 fathoms, while the eastern entrance possesses only 14 fathoms at its seaward end. The deep western channel, like the deep eastern channel on the southern side, shows an extension inwards into the lagoon of the reefs on its two sides, and here also there are several small shoals just inside the entrance. As on the south side, this difference is correlated with the different behaviour of the tides in the two entrances : through the western channel the tide sets into the lagoon on the flood and out from the lagoon on the ebb, but in the eastern channel the current runs out from the lagoon at all states of the tide. Stanley Gardiner stated (1903) that these northern channels were closing up owing to the growth of coral in them, and that, in consequence, they were no longer used by native craft ; in this, however, he seems to have been mistaken. Soundings taken by us in 1934 show that the depth of water at the present day agrees closely with what Moresby found in 1836, so that there has been little or no change in the period of 100 years. The explanation of Stanley Gardiner's mistake is probably to be found in the fact that he was in Addu atoll in the month of April, and that at this period of the year the prevailing wind is from the north-west. The most important fishing villages in the atoll are Midu and Huludu, and these are situated in the north-east corner of the lagoon. As the native boats are very bad at beating to windward, which would be necessary in order to leave the lagoon by the northern entrances, when the wind is in the north-west quarter, the fishermen leave the lagoon by running before the wind through the south-east entrance. On their return they land opposite the village on the outer reef, the boats being run in on the top of a wave and then rapidly pulled up the reef before the next wave breaks. They are subsequently pulled over the reef and through the channel between Huludu and Putali to the lagoon to be ready for the next day's fishing. In this way a long detour round into the lagoon is avoided and there is no necessity to use the northern channels. They, however, do so occasionally, and all dhows coming from the atolls to the north of Addu, during the time that I was in the atoll, entered the lagoon through one or other of the northern channels.

THE REEF PLATFORM.

A study of the reef platform shows that even in the same atoll there may be a very considerable variation in the width from sea face to lagoon margin. In Addu atoll the narrowest part of the reef platform is to be found on the northern side ; here the distance measured radially from the outer fissure zone to the inner lagoon reef is roughly 500 yards. On the east side of the atoll the width of the reef platform is about 1200 yards, while on the west and south-west sides it is as much as 1700–1800 yards. These differences seem sufficiently great to demonstrate that reefs may, even in the same atoll, vary enormously in width, but if we consider the distances between the lagoon reef and the reef face in the two horns, at the north-east and north-west corners, the difference is increased enormously. In the north-east area the distance from the lagoon reef to the reef face, measured radially, is as much as 4000 yards, while in the north-west part, where the island Hitadu projects outwards, it is as great as 6000 yards, so that at this point the width of the reef is at least ten times as great as it is along the northern side of the atoll.

THE OUTER REEF.

The outer part of the reef lying between the seaward face of the islands and the reef margin agrees very closely with the descriptions given by previous authors of the corresponding part of the reef in other atolls ; but there are certain differences in the character of the reef on the two sides of the atoll.

The edge of the reef is, as usual, composed almost entirely of nullipores, most of them being of a dull red colour, and it is cut into buttresses and deep channels, through which the water pours back off the reef after each succeeding wave. Even after the cessation of the north-east monsoon there is a heavy surf breaking on this part of the reef, and this renders a close inspection of its more detailed features impossible. The fissure-zone slopes slightly upwards to the seaward flat of the reef, but few, if any, of the fissures actually penetrate as far as the top of this slope, the reef crest (Pl. I, fig. 1).

Commencing at the eastern horn and following the outer or seaward flat to the south, to the east of Midu-Huludu Island the flat is comparatively wide and the outer edge, between the reef flat and the Buttress and fissure zone, is raised along its whole length about a foot above the general level of the flat. At the southern end of the island opposite the village of Huludu and between it and the next island to the south, Putali or Heratera, there is a wide bay, which is covered by a depth of about 9 in. of water at low-water spring tides except on the inshore side of some masses of rock on the flat, where the depth of water is deeper owing to scouring out of the floor to a depth of an additional foot or so. The floor of this bay is almost entirely covered by a bed of coral fragments and sand, the latter occurring in patches, and the whole is densely overgrown by a profuse crop of a red or green grass-like weed (*Cymodocea* ?). Commencing on or near the reef crest several spits of broken coral and small boulders run inwards across the flat towards the islands. From the south-east point of Huludu a line of coral rock, about 3 ft. in height, extends. like a broken wall from north to south across the bay (Pl. I, fig. 2, and Pl. II, fig. 1), and at its southern end merges into the piled-up masses of coral boulders on the sea face of the island of Putali. The rock of which this wall is composed consists of lumps of broken and water-worn coral, together with shell fragments, etc., embedded in a coarsely granular

matrix that resembles sandstone. The luxuriance of the growth of the weed on this flat is probably attributable to "manureing" by the inhabitants of the neighbouring fishing village, Huludu, and the flat possesses a rich fauna ; lying on the reef were several large black Holothurians and a number of examples of *Synapta*, while two or three eels of a species of *Muræna* were seen, as well as numerous small fish that were darting about in the weed and small crabs crawling over the coral fragments.

Stanley Gardiner remarks, "the presence of conglomerate masses I can only regard as indicating the existence of former land masses in any position", an opinion with which I entirely agree ; and it seems to me that we have in this ridge of rock stretching across the bay the still-persisting remains of the outer line of an old connection between Huludu and Putali, which has subsequently disappeared owing to erosion. On the south-west side of the bay at a little above high-water mark on the beach of Putali there is a small outcrop of a conglomerate rock, consisting of masses of coral, for the most part water-worn, shells, etc., and the varied position of the coral masses undoubtedly indicates that these have not been embedded *in situ* as they were growing, but have been piled up, some sideways, others upside-down, and have subsequently been consolidated. In the chart of the atoll given by Stanley Gardiner (1903, p. 415), which is based on the observations made by Capt. Moloney and Forster Cooper, a small crescentic island is shown lying to the outer side of the gap between Huludu and Putali, but at the present time the only indication of the former presence of any such island is the line of coral rock referred to above, and there is evidence on both the north and south sides of the bay that the sea is encroaching.

Between the two islands, Huludu and Putali, a channel runs from the outer reef to the lagoon. This channel runs at first westwards and then turns northwards for a short distance, after which it again bends to the west and then north, before finally turning sharply westward to enter the lagoon opposite the middle of the area of "foul ground" that occupies the north-east corner. On the northern shore of Putali and along the south side of the channel several palm-tree stumps are to be seen standing on the reef flat or at the margin of the channel, and the south side of the channel itself shows clear erosion in the presence of a steep bank down to the water, whereas on the northern side the bank shows a gently sloping beach of coral fragments (Pl. II, fig. 2).

Along the east side of Putali and the islands lying to the south of it the reef flat is comparatively narrow. As one traces it inwards from the nullipore zone one finds that the flat itself has a comparatively smooth surface, thickly dotted over with water-worn, usually flat, coral fragments, that are in the main aggregated into definite spits running out from the island (*vide* Pl. III, fig. 2). Agassiz (1903, p. 146) describes this area as follows : "The eastern edge of the reef flat is edged by a wide belt of masses of boulders reaching the very base of the shingle beaches on the outer face of the islands." On the inner side of the reef flat this boulder-layer slopes slightly upwards to join the island beaches, or else terminates in a slightly raised cliff of coral rock. Even at low tide this part of the reef flat is for the most part covered by about a foot of water, but along the outer edge of the reef flat a succession of coral masses are exposed above water. Opposite Mulikadu Island, which is the southernmost island on the eastern part of the reef, a small spit of piled-up coral fragments runs across the reef flat (*vide* Pl. VI, fig. 1), and in the shallow water to the south of this spit are a number of circular flat colonies of *Porites*, each being about 3 to 5 ft. in diameter, and showing live coral at the sides and a dead, eroded upper surface.

PACIFIC OCEANIC FISHERIES
INVESTIGATIONS

Along the whole length of the reef flat on this east side of the atoll I was unable to find a single "negro-head", and at low tide but little of the outer zone was exposed above sea-level.

On the south-west side of the atoll the outer reef differs in several points from that on the eastern side. The margin of the reef to seaward, *i. e.* the nullipore zone, is of the usual type and is similarly cut into buttresses and fissures, the whole being overgrown with nullipores. The fissure zone slopes slightly upwards to the level of the reef flat, which on this side is much wider in the greater part of its extent than on the east side. The outer part of the reef flat is here occupied by a broad boulder zone that is well exposed at low water, and consists of numbers of loose water-worn coral blocks and fragments that together form a slightly raised ridge, running along the outer part of the reef. Running inwards towards the islands with a north-easterly trend are numerous spits, composed of loose piled-up blocks of coral, and to the south, at the south-west point of the reef, this boulder zone merges in a series of eight small islets, composed entirely of piled-up coral boulders and coral rock (Pl. II, fig. 3).

Along the boulder zone on this aspect are scattered several large masses of coral, rounded and water-worn, which, though small in comparison with the blocks seen on islands in the Pacific Ocean, I have called "negro-heads". These have undoubtedly been torn off the outer face of the reef and have been hurled inwards and upwards on to the reef; the mass in the foreground in the photograph (Pl. II, fig. 3) shows clearly the broken base, facing the observer, and two rounded heads of the main coral growth; there can be no question that this fragment, now lying on its side, has been torn from its original site and flung on to the reef, and is not a dead mass of coral that originally grew in this position.

Inside the boulder zone the reef flat, even at low-water, is covered by about a foot of water, and along the south-west part of the atoll the flat presents several marked points of difference from the reef flat on the east. Extending in a line from just inside the series of small islands, that I have mentioned above, at the south-west point of the reef towards the north as far as the channel between Maradu and Hankadu Islands, is a series of "coral horses", from $2\frac{1}{2}$ to 3 ft. in height and composed of a hard, compact coral rock. Outside this line the reef flat is composed of a smooth, hard stone that appears to consist of coral masses cemented together. Inside the line of coral horses the character of the flat is different, and it consists for the most part of sand and beach sandstone, with scattered lumps of dead coral and occasional small colonies of *Heliopora* and madrepore, while large areas are covered with a considerable growth of a grass-like, red-brown alga, having blades from 2 to $2\frac{1}{2}$ in. in length (*Cymodocea* ?). On the shore side of the coral horses banks and spits of coral shingle have been piled up and run inwards towards the islands (Pl. III, fig. 1).

Further to the north the islands of Abuhera and Hitadu lie further out on the reef, which in this part closely resembles the reef flat on the east side of the atoll, and an outer rampart of water-worn coral blocks has been piled up along the island margin, very similar to that seen on the east side of Putali.

There can be little doubt that the differences in the reef flat on the east and west sides of the atoll are due to the different effect of the two monsoons. In spite of the atoll lying to the south of the equator and, therefore, more or less out of the main area affected by the south-west monsoon, the effects of the south-west winds are obviously considerably

greater than those of the north-east winds. On the south-west side of the atoll the waves have piled up coral blocks on the reef to a much greater extent, and have even at times torn off and thrown up large masses of " negro-heads ", which are never seen on the east side.

At the extreme south-west corner and along this face of the atoll the winds and waves, by erosion of the outer face and the deposition of sand on the inner, have driven the islands inwards across the reef flat for a very considerable distance, thus increasing the width of the outer reef flat (boat channel), and leaving behind as an interrupted ridge a line of coral rock that originally formed part of the base of the islands. The condition here exactly agrees with the account given by the Coral Reef Committee of the Royal Society (1904, p. 71), which points out that in the atoll of Funafuti " in some cases there is an outer line of extremely dense breccia, marking the most advanced position oceanwards occupied by that material at a time when it formed the foundation for islets which have since been driven inwards over the reef platform towards the shore of the lagoon ".

The northern reef, which is interrupted somewhat to the west of the middle of its length by the two entrance channels, differs from the rest of the reef by being almost entirely devoid of islands along its whole length. A few small islands stretch westwards for a short distance from the north-east point of the atoll, and the isolated portion of the reef, between the entrance channels, bears one small island, " Bushy Island ", and several small sand-cays. These sand-cays all possess the same shape and are crescentic, with the horns of the crescent pointing towards the west ; it appears probable that they have been built up of drift sand during the north-east monsoon. The character of the northern reef differs markedly on the two sides of the entrance channels. On the east side the edge of the reef is everywhere composed of growing coral, whereas on the west side there is a well-marked, raised boulder zone, composed of piled-up masses of coral boulders. This difference I attribute to the general trend of the reef ; on the west side of the opening the reef is exposed to the full force of the north-east monsoon, whereas on the east of the opening it is more or less sheltered from it by the projection of the north-east horn of the atoll, or at the worst is only raked by it.

THE ISLANDS OF THE REEF PLATFORM.

In most of the smaller atolls of the Maldive and Laccadive Archipelagos the main islands lie on the eastern side ; at the southern end of the Maldives in both Addu and Haddumati atolls the north-east corner is occupied by a large island ; further north, in Horsburgh atoll, the chief island, Goidu, lies on the north-east side ; while further still to the north, in Minikoi and the Laccadive group, the main islands are situated on the east or south-east rim of the atoll ; and in a previous paper* I have attributed this to the effect of the south-west monsoon wind and sea.

Commencing at the north-east corner of Addu atoll we have the island of Midu-Huludu. There appears to be no special name for the island itself ; the names Midu and Huludu refer to the two villages that lie respectively at the north and south end of the island, but the former, Midu, has been applied by previous writers to the whole island. The island itself is roughly triangular in shape, its apex, with the surrounding reef, forming

* ' Mem. Asiatic Soc. Bengal,' vol. ix, pt. 8 (1935).

a well-marked projection towards the north-east. Stanley Gardiner (1903, p. 151), from his survey of the island, concluded that since the original survey by Moresby the north-east corner of the atoll and presumably therefore the north-east corner of Midu Island was growing outwards. A comparison of Moresby's and Gardiner's charts and the present state of affairs certainly appears to warrant this conclusion, and the structure of the island indicates that the extension, if it be real, has been brought about by the deposition of sand derived from the reef flat. Stanley Gardiner (1903, p. 417) describes the general structure of this island, as it existed in 1900, as follows : " Round the seaward side of the whole island, except at the extreme south end, the rock forms a narrow line, its greatest height about 5 ft. above the high-water mark." At the time of my visit the whole of the beach at the north-east corner and along the east side was composed entirely of sand and fine coral debris, mixed with shells and fragments of dried sponge, and a rock wall only appears at the southern end of the island (Pl. I, fig. 2). Along the east side of the island there is a belt, about 7 to 8 yards wide, between the thick jungle and the beach, and this is covered with weeds and a bush " scrub ", so that it seems probable that this strip of land is a recent formation ; this belt disappears at the southern end of the east side, where evidence of erosion can be seen. It would thus seem probable that Midu has to some extent grown outwards, and that this is due to the deposition of sand on its leeward shore during the south-west monsoon seasons.

The central portion of the island, which is thickly wooded, is depressed and is occupied by a large swampy area, in the centre of which is a stretch of open water about 200 yards long.

The inner or western shore of the island runs nearly straight in a north-south direction, except at the south-western point, where there is a small projecting area from which a small sand spit runs northwards, parallel to the shore, across the reef flat, and there is no raised inner rim or " lagoon-mound ". Stanley Gardiner has called attention to the formation of this spit, and he remarks (1903, p. 417), " it is evidently growing northwards and appears likely in course of time to cut off another " kuli " (water pool) from the sand flat ". The spit certainly appears to be growing, and is now Y-shaped, one arm running northward, parallel to the shore of Midu, while the other bends to the west, and the native inhabitants have built up a causeway across the mouth of the little bay thus formed, so as to complete the enclosed basin, the water of which is brackish. This spit is evidently caused by the current of water that flows from the outer reef flat between Midu and Putali islands ; the channel, which at first runs westward between the islands, turns to the north and is continued between the projecting south-west part of Midu and the narrow northward prolongation of Heratera, and then again swings westward to enter the atoll.

From the north-west corner of Midu a string of small linear islands runs westward along the reef flat ; this chain shows very interesting changes since its original survey in 1836. Originally six in number, in 1900 Stanley Gardiner found two small islets near the north-west corner of Midu, followed, after a small interval, by a chain of five more, that gradually decreased in size towards the west. In 1934 there are three islets near the north-west corner of Midu, and then, further to the west, come two more, of which the easternmost is narrowly linear and seems to have been formed by the fusion of other smaller islets. The last small islet in the series lies to the west of a linear strip of coral rock. A comparison of Stanley Gardiner's chart (1903, p. 415) and the condition of the

present day seems to indicate that the easternmost island, Balihura, has been broken up, and is now represented by the two small islands lying nearest to the north-west corner of Midu. Hika, the second of the series, appears to have remained more or less unaffected. After an interval we get at the present time the linear island that seems to correspond to the island Hera in Stanley Gardiner's chart, or possibly to that and the next following island ; but between this and the small island on the extreme west, which still survives, at least two islands have disappeared, and are now only represented by the line of coral rock to which I have already referred. It would appear probable, therefore, that these islands are also undergoing erosion.

The next island, to the south of Midu, is Putali (or Heratera), and both it and two other small islands still further to the south appear to have been derived from the breaking up of an originally single island, called Putali on Stanley Gardiner's chart (1903, p. 318). At the present day the island of Putali is long and narrow, and there were certain indications on both sides at the time of my visit that it was slowly being washed away. One would, however, have to visit these islands at different times of the year before one could decide with absolute certainty how far such an appearance of erosion is permanent or only temporary, as the local conditions differ markedly from season to season, owing to the alternating action of the two monsoons. In this connection I may note here that, as regards the islands on the western side of the atoll, the Head-man informed me that the area of land is continually altering with the season ; during the north-east monsoon the inner perimeter of these western islands, *i. e.* the lagoon side, is washed away, the degree of such erosion depending apparently on the strength of the monsoon, and on one island a strip of land bearing twelve palm-trees was thus eroded away in a single season ; at the same time the western or leeward side of the island tends to become increased in area. The opposite change takes place during the south-west monsoon ; the lee side, towards the lagoon, then enlarges, and the windward side tends to be washed away. The same process, must be going on in the islands on the east side of the atoll, though here the action of the south-west monsoon will not be so effective as that of the north-east monsoon since the height of the waves in the lagoon will be markedly less than that of waves in the open sea, though probably sufficient to cause a certain amount of erosion along the lagoon beaches, which will be to some extent, and possibly entirely, compensated by deposition of sand and a consequent extension eastward of the island, as seems to have been the case in the north-east part of Midu. During the north-east monsoon the reverse process will be set up, the island being washed away on its eastern side and a deposition of sand and a consequent extension taking place on the western or lagoon side.

A study of the two charts of this atoll, made respectively in 1836 and 1900, and a comparison with the condition present in 1934, reveals an interesting series of changes at the north end of this island, Putali. Originally, at the time of Moresby's survey, this island formed a long stretch of land along the eastern rim of the atoll, and to the south of it lay two smaller islands, followed, after an interval, by a third ; sixty-four years later, when Stanley Gardiner visited the atoll, it was found that a small island existed between Putali and Midu ; this, presumably, had been derived by the formation of a breach across the northern end of Putali, or possibly the southern end of Midu. Stanley Gardiner (1903, p. 47) remarks that " from the appearance of the channels through, to the N. and S. of Putali, it seems to me to be probable that the islands are coming together to form one continuous whole ". The conditions present in 1934 show, however, that the change

that has been going on to the north of Putali is not quite so simple as this. Putali and the small island to the north of it certainly may have joined but, as already shown, the bay between Huludu and Putali is slowly but steadily extending, and the northern part of the small crescentic island that in 1900 lay on the reef between the two islands has now, so far as I can judge, completely disappeared, though its former position may still be indicated by the interrupted line of coral rock that runs across the bay. In all probability the sand, that has been derived from the disintegration of the northern end of the island and from the erosion of the eastern shores that has formed the present bay, is being swept through the channel between the two islands, and is being deposited on the northern end of the spit that runs out from Putali on the lagoon side, since this appears to be extending northwards up the south-west side of Huludu, and its proximal part is gradually becoming covered with a low bush scrub, though the terminal part is still bare.

The structure of the three islands on the east side of the atoll, namely Putali and the two islands to the south of it, agrees closely with the description given by Stanley Gardiner of Minikoi (1903, p. 29). As already mentioned, in the northern part of Putali there is an exposure of old coral rock, which is now undergoing erosion (Pl. III, fig. 2). The seaward side of these islands consists of a raised rim of coral rock and boulders, while the western or inner side is composed of sand and shingle. As in other islands, the breadth of this seaward stony area varies in different regions of the same island, and in places it is a matter of some difficulty to draw a dividing line between it and the sandy inner part of the island, the coral boulders gradually getting fewer and fewer, so that the two areas grade imperceptibly into each other. The outer beach of Putali comprises several distinct zones. Along the outer margin (Pl. III, fig. 2), where the island abuts on the reef flat, there is a typical boulder zone, composed of numerous large lumps of water-worn coral, which at certain points are aggregated together to form spits that run out from the island towards the edge of the reef across the reef flat ; it is impossible to say to what extent these coral boulders are derived from masses that have been torn off the reef edge, and have been flung inwards by the action of the waves, or from the gradual breaking down of the old reef rock by erosion and the consequent setting free of masses of coral that originally were embedded in it ; probably both sources of origin are concerned, at any rate at the northern end, where the old rock is exposed and is undergoing erosion. Inside this boulder zone is a belt consisting of water-worn coral blocks mixed with sand, and, finally, the beach rises abruptly and is composed of water-worn slabs of coral ; this rampart of coral blocks (Pl. IV, fig. 1) is several feet, usually three or four, in height above the general level of the island, and its inner landward side shows a gradual and typical " scree " slope. Many of these fragments are so water-worn that they now resemble fragments of flat paving-stone.

Towards the south end of Putali this rampart-like ridge of coral blocks gradually disappears and the beach becomes an ordinary shelving one, sloping gradually upwards from the sea-level ; this part of the beach is composed of much smaller fragments of broken coral, with which a fair quantity of sand is intermingled. Between the two extremes of a high wall to the north and a shelving beach to the south is a region in which the beach consists of a double ridge, a high inner one composed of comparatively large boulders, which corresponds in position and general structure with the rampart-like ridge to the north and which falls away steeply on its seaward face, and a second lower ridge, composed of small coral fragments, forming a coarse shingle. Between these two ridges there is a trough-like depression. At the edge of the beach, near the water-level, is a belt of coral

rock consisting of fragments of coral much water-worn and cemented together by sand and debris. Stanley Gardiner (1903, p. 31), in his account of the atoll of Minikoi, has described a rampart-like ridge, very similar to that seen on Putali, but in consequence of a greater degree of erosion the face of the ridge is considerably steeper. In the case of the ridge on Putali the talus slope on the landward side shows clearly that the ridge has been thrown up, and I am inclined to regard it as the old boulder zone that was raised to its present height when the fall of sea-level brought the whole reef above the surface. Stanley Gardiner (1903, p. 417) has called attention to the fact that " Putali at its most southerly seaward point has also some fallen shrubs, but elsewhere none of the islands (of the eastern side of the atoll) showed any distinct change in progress ". At one point on the east side of Putali the sea has actually broken through the outer rampart, while at about the middle of the length of the island on the seaward side there is clear evidence of erosion going on. Here the shore curves inwards in a shallow small bay and the basal rock is well exposed, while the beach behind it also shows evidence of washing away in the shape of a steep fall from the top and the presence of bushes, that in other parts of the island rim are found growing just inside the top of the ridge of the outer beach, here standing on the seaward face of the rampart ; in addition fresh white masses of coral have been recently flung inwards over the top of the older black and water-worn boulders.

On the western side of the island, *i. e.* the lagoon side, the beach is composed almost entirely of fine sand, which gradually slopes upwards from the sea-level to the top of the ridge or " lagoon mound ", where this exists, for it is not present in the northern part of the island (Pl. IV, fig. 2). The contrast between the sand of the ridge and the inner reef flat, which consists of sand mixed with numerous small fragments of coral derived from the lagoon reef, is a marked one, and can clearly be detected all along the island when the tide is sufficiently low to expose the inner part of the reef flat.

At intervals along this beach there is also evidence of erosion ; at the extreme north end, where the island forms a well-marked promontory, the lagoon mound is absent, and several palm-tree stumps are standing on the lower slopes of the beach, and other palm trees have actually fallen owing to the sand surrounding their roots having been washed away. About half-way down the island the lagoon beach again shows clear signs of erosion, for at the top it terminates in a small cliff about 1 ft. high, and a number of bushes are actually standing in the water at high tide. Along this part of the beach there is a linear outcrop of sandstone that is horizontal, not sloping, like beach-sandstone, towards the lagoon ; it seems probable that this sandstone is part of the cay-sandstone that has formed beneath the sandy soil of the island and is now being exposed by erosion. The outcrop is situated almost exactly midway between the top of the beach and high-water level, and extends along the beach for some twenty yards or more (Pl. IV, fig. 3).

Towards the southern end of the island there is a slight indentation in the coast-line, and here the shrubs, which usually grow at the top of the beach, come right down to the high-water mark, and are in many cases being killed off by the salt water, and beyond this the stumps of others can be seen standing up out of the sand. All along this part of the beach there is an outcrop of beach-sandstone. At the extreme south end of Putali there is further evidence that the sea is encroaching on the land, for all along the beach are fallen trees, and in many places coco-nut palms, that are still standing, have their roots exposed owing to the sand having been washed away.

Every island along the eastern face of the atoll has at least one " kuli " or lake, and

in the case of Putali there has been a series of them extending along the whole length of the island. Stanley Gardiner stated that in 1900 there were about twelve, but owing to the continual deposition of sand on the southern part of the island many of these have now been filled up, and their original sites are only indicated by areas of dried mud, on the surface of which lie thousands of dead shells of *Pyrazus palustris* (Linn.). In this island the process of formation of these lakes appears to have been repeated, so that the lakes or pools form two series down the length of the northern part of the island. One series, representing the earlier formation, lies along the east side of the island close to the foot of the talus slope of the outer rampart ; there are in all three pools in this situation, each of them containing brackish or salt water. The most northern (Pl. V, fig. 2) is the only one of the three that appears to have retained its original condition ; in this the water has a salinity of 5·23 and a specific gravity of 4·15. The second of the series possesses a figure-of-eight shape and appears to have attained its present form by the union of two pools, one belonging to the earlier formation and the second to the later one ; here again the water is brackish and has a salinity of 7·30. The last of the older series lies towards the south end of the island and also appears to have been formed by the union of two originally separate pools, both of which in this case, however, belonged to the early formation ; at the northern end of this southermost lake the sea has within recent times broken its way through the coral rampart on the east side of the island, so that this now contains salt water ; incidentally this provides further evidence that there is a process of erosion going on.

The second series of pools lies close to the western shore of the island in its northern half ; they form a chain along a low-lying belt, that is bordered on its west side by the raised sandy lagoon-beach, while the eastern boundary is a steep sandy bank (Pl. V, fig. 1). These lakes would seem to be of comparatively recent formation. Running along the whole length of the northern part of the island, about 10 yards to the east of the steep bank that now forms the east bank of the lakes, there is a well-marked line of rounded, water-worn pieces of pumice. Stanley Gardiner (1906, p. 582) remarks, " One may point out that on the shores of many of the islands there are lines of pumice, which the natives state were washed up about 1885, and would hence have probably owed their origin to the eruption of Krakatoa in 1883. In addition, half-decomposed pumice is found, in places at some considerable distance inland, which evidently belonged to an earlier period ". The pumice that lies along this east bank of the lakes is little, if at all, decomposed, though it has become stained a brown colour, owing probably to contact with vegetable mould. Oldham (1895, p. 6) has recorded a similar deposit of pumice on Kardamat Island in the Laccadive Archipelago, and he remarks that " it is strewn all over the surface and varies in size from a marble to half a foot in diameter ". There can, I think, be little doubt that this deposit was derived from the explosion of Krakatoa, and that it was drifted up on the lagoon beach of the atoll at some subsequent period ; if this be so, then since 1885 or thereabouts the inner beach of the island has advanced towards the lagoon by some 10 yards, and sand spits have been built out into the lagoon and have cut off the lake, forming a new lagoon beach on its western side, that in turn is also about 10 yards wide. All of these lakes of the second series, of which there are now three, the fourth having, as stated above, become fused with one of the lakes of the older and outer series, contain water that is only very slightly brackish or very nearly fresh ; the specific gravity and salinity in these lakes, as we proceed from north to south, is as follows :

No.	Specific gravity.	Salinity.
1. Northernmost . . .	0·89	1·21
2. Middle	2·13	2·74
3. Southern	2·25	2·88

All these pools possess one peculiarity in common, namely, that the water-level in them tends distinctly to rise and fall with the rise and fall of the tide, and this change is much greater at spring tides than at neaps. The regular ebb and flow of the water in wells on coral islands was noticed by Darwin in his account of the voyage of the "Beagle"; he remarks: "At first sight it appears not a little remarkable that the fresh water should regularly ebb and flow with the tides; and it has even been imagined that sand has the power of filtering the salt from the sea water. These ebbing wells are common on some of the low islands in the West Indies."

The fauna of these lakes presents several features of interest; since the lakes were originally part of the lagoon, one would naturally expect to find that the fauna was of an essentially marine type, and for the most part this is the case. Most, if not all, of the lakes, even the northern one that contained nearly fresh water, were inhabited by numbers of the Silver Mullet (*Chanos salmoneus* (Forsk.)), and contained large numbers of a species of *Leander* and numerous Amphipods, while the lake margin was frequented by enormous numbers of the mollusc *Pyrazus palustris* (Linn.). In one of the more recently formed pools on the west side of the island, however, were numbers of a species of *Melania*, a fresh-water species that must by some means have been imported. All around the margins of the lakes are numerous burrows of the large land crab, *Cardiosoma carnifex* (Hbst.), and as one walks through the scrub-jungle covering the middle and southern parts of the island one of these crabs or its hole is seen every few yards.

Continuing southward along the eastern rim of the atoll from Putali, we come to two small islands, Firai-du-hera and Kalu-hera, both of which, as their names would seem to imply, appear to have originally formed part of the island of Putali (or Heratera), but have since become separated from it. Moresby, in his original chart, made in 1836, shows two islands in this situation, the southern one being by far the larger of the two; Stanley Gardiner, on the other hand, only shows one. It is therefore a matter of very considerable difficulty to determine what changes have taken place in this part of the atoll but, so far as one can judge, the three islands, Putali and the two to the south of it, as shown by Moresby, became fused into one; at the north end a small island became separated off, as shown by Stanley Gardiner in his chart; and since 1900 there has been still further attrition, resulting in the disappearance of this separate island, partly by erosion and partly by fusion with the north end of Putali (now called Heratera), and the extension northwards of the main island on the inner and west side of Midu, while at the extreme south of Putali (or Heratera) two small islands have become separated off to form Firai-du-Hera and Kalu-hera. Both Moresby and Stanley Gardiner show only a single island in this position.

At low tide a ridge of solid coral rock, with a few slabs of water-worn coral scattered over it, connects all three islands, and the outer margin of each island between tide-marks consists of the same material and presents the same character. On the lagoon side of this connecting ridge between Putali and Firai-du-Hera the sand has been washed away by the inrush of water over the ridge at high tide, and, in consequence, there has been

formed a small but comparatively deep bay in which a few scattered colonies of a species of *Euphyllia* (?) are maintaining a precarious hold. At the north end of Kalu-hera is a small pool of salt-water that on its outer or seaward side is separated from the sea by a raised ridge of water-worn coral fragments, that drops steeply into the pool; judging from appearances the sea has comparatively recently broken through into the pool; the west and south sides of the pool are formed of gently-sloping mud and sand, in which a clump of mangrove trees are growing; these trees, though small and attaining a height of only 6 to 8 ft., are perfectly typical in character; the type of the fauna in the pool is essentially marine.

The last island on the eastern portion of the rim of the atoll, Mulikadu, is situated at a considerable distance from Kalu-Hera, though connected to it by a raised ridge of coral boulders, against which sand and shingle have drifted on its lagoon face. The position of this island is much further from the south-east entrance channel than is shown on the charts by either Moresby or Stanley Gardiner. The structure of the island is peculiarly interesting, in that it differs in several particulars from the other islands of the eastern rim, and forms one end of a series of which the island Midu is the other. Whereas Midu consists almost entirely of sand, Mulikadu consists almost entirely of coral boulders and shingle, and both inner and outer beaches are steep. The outer seaward beach has a marginal zone of coral rock that is raised some 2 to 3 ft. above the level of the reef flat, and immediately above this is a zone of loose coral boulders. Then comes a dazzlingly white steep beach of coral shingle, on which, at the time of my visit, numerous Terns, *Sterna melanauchen*, were breeding, their eggs being deposited on the shingle in ones and twos all along the beach (Pl. VI, fig. 1). The only other island on which these terns were breeding was a small sandy islet in the middle of the lagoon. At one point a narrow spit of coral boulders runs outwards from the island across the reef flat. The lagoon beach rises steeply from the water-line and, instead of being composed of sand, as in all the other islands on this side of the lagoon, consists of small water-worn coral boulders or fragments, so that it more closely resembles in its general appearance one of the seaward beaches. The surface of the island consists entirely of coral fragments or shingle, and looks as if it had been ploughed up by an enormous plough, ridge after ridge of coral and shingle having been thrown up, each one following the line of the inner margin of the island, and thus showing where from time to time fresh additions to the island have been piled up on its lagoon aspect. I have already mentioned (*vide supra*, p. 65) that at certain times of the year the north-west wind blows strongly, and that the effect of cyclones in the Laccadive Sea will be to cause strong gales from this quarter; and it is just at this point on the rim of the lagoon that the effect of such storms will be most strongly felt. It would appear from the structure of the island that during such gales the waves in the lagoon have sufficient force to cause the piling up of comparatively large coral masses, instead of the usual sand; further evidence of the growth of the island inwards towards the lagoon is to be found in a well-marked line of deposit of water-worn fragments of pumice that was, as in the case of the similar deposit on Putali, almost certainly thrown up after the explosion of Krakatoa in 1883; this line of pumice is now at a distance of some 20 yards from the top of the lagoon beach, indicating that this amount has been added to the island since that date. At the south-west end the island tapers to a point, and the upper ridge of the outer beach cuts sharply across the ends of the ridges of the inner part of the island; continuing the line of the island and running out in a south-westerly

direction is a spit of broken, water-worn coral, and beyond this the line of the reef is continued to the south-east entrance channel. The surface of the island is covered with low bushes, and in the central part there is a sunken area containing a small pool of very nearly salt water. The floor of the pool consists of a soft flocculent mud, forming a layer a few inches thick, below which there is a level hard rocky floor, that is undoubtedly part of the old reef flat. Living in the pool were numerous molluscs, and scattered here and there were masses of sponge, black in colour and with long digitiform processes, as well as patches of weed, on the branches of which were large numbers of a sessile Tunicate and several small brown Actinians, while numerous polychæt worms and amphipods were crawling in and out of the tangled masses of the weed clumps.

On the isolated part of the reef that lies between the two southern channels is situated the island Wiringili. As Stanley Gardiner (1903, p. 419) has pointed out, this island has been formed by the fusion of the two islands that were present on this part of the reef when the original survey was made by Moresby in 1836. Like Midu, the island is covered with trees and jungle, and in the centre of the eastern part of the island there is a pool of absolutely fresh water. A small isolated rocky islet lies to the south-west near the channel between Wiringili and Gan Islands.

A glance at the chart shows that the majority of the islands on the western part of the rim of the atoll are larger than those on the eastern side, and are situated much nearer the inner margin of the reef platform ; they are all separated from one another by channels through which, even at low tide, the water on the outer reef flat has direct access to the lagoon ; these islands are also much more heavily wooded, except in one or two small areas, than the eastern islands, and instead of being covered by a low bush-scrub, they bear a number of large trees, conspicuous among which is the Jack-fruit Tree.

Commencing at the southern end, the first island is Gan, situated close to the inner reef and heavily wooded ; its northern shore lies close to the lagoon reef, but separated from it by a boat-channel. Both northern and southern shores are sandy and, judging from previous charts, the island appears to be gaining in size, on both faces.

The next island, Faidu, is also thickly wooded, and the beach at its north-western end consists entirely of sand, sloping gently upwards from the water level to the general level of the island. Stanley Gardiner (1903, p. 419) has called attention to the fact that on its seaward side this island is being washed away : " On the seaward side of the east end of Faidu there is a good deal of fallen timber, showing washing away, and between the island and the boulder zone are no less than 15 masses of rock on the reef." As I shall have occasion to point out later, this process, which is, I think, more of the nature of an " inward drift " across the reef flat than one of simple erosion, the area lost on one side being added to the island on the other, has affected all the islands on this part of the reef flat to a greater or less degree. Between Faidu and the next island, Maradu, is a deep channel, which, however, shoals considerably at its inner lagoon end, where a bar of sand and rock tends to connect the two islands ; even at low-water this channel does not dry completely ; patches of rock project above the surface, but do not prevent the free access of water from the outer to the inner reef flat. It is probable that this line of rock represents a former connection between the two islands.

On the west side of Faidu and opposite the channel between it and Maradu Island there is a series of six small islets, situated on the boulder zone close to the edge of the reef. Between these islets and the islands of Faidu and Maradu there is a wide shallow

channel, the floor of which consists of sand and coral fragments, with here and there small isolated colonies of *Porites* or Astræidæ and a small quantity of weed. On the east or shore side of this group of islets, but separated from them by a narrow channel, is an outcrop of coral rock, about 1½ or 2 ft. in height. The islets themselves are situated on the edge of the boulder zone and, like the islands on the eastern part of the atoll, their seaward face in most cases consists entirely of a ridge of water-worn coral boulders, at the foot of which, on the sea side, is a belt of coral rock. The inner face of these islands consists of sand and shingle. The most northerly of the series differs somewhat from the others in that it consists of a mass of exposed coral rock on its seaward face, against which coral shingle and sand has been piled up, and now forms several spits running across the reef flat towards the inner islands; in this respect it more resembles the small isolated islet that is situated further to the north on this side of the atoll opposite the island of Hangadu. Some of these islets are entirely destitute of vegetation, but on the largest of them there is a low scrub jungle, composed of bushes similar to those found on the islands on the eastern part of the rim, and a few palm trees have maintained a hold on the sandy area to the east of the boulder ridge. Spits composed of coarse coral shingle and small boulders run inwards from several of these islets towards the island of Faidu, only a narrow strip of water, about 6 in. deep, separating them from each other at low tide.

Stanley Gardiner (1903, p. 419) called attention to the presence of these islets on the outer reef flat, which were unrecorded on Moresby's original chart; at the time of his visit in 1900 there were " seven small uncharted islands between Faidu and Gan and the seaward edge of the reef. The first of these is a small stony islet just inside the boulder zone opposite the centre of Gan ". This is still present, but appears to be much reduced in size. " Then there is a sandbank in the corresponding position of the west end of Gan "; this has now disappeared. " Off the centre of Faidu, and opposite the passage between Faidu and Maradu, was a large coco-nut-covered island, with outside it three smaller islets covered with low bushes, an additional stone bank with a few shrubs lying to the north." If we number Stanley Gardiner's series from 1 opposite the middle of Gan to 8 at the extreme north of the series, and compare them individually with those now present, it seems, as mentioned above, that No. 1 is still present, though reduced in size; No. 2 opposite the western end of Gan has completely disappeared, and so probably has No. 3 opposite the channel between Gan and Faidu. No. 4 is present, though to all appearances somewhat reduced in size. Nos. 5 and 6 appear to be unchanged. No. 7, the largest of the series at the time of Stanley Gardiner's visit, appears to have now been broken up, some of the coco-nut trees still managing to survive, but the washing away of the inner part of the island has laid bare the mass of coral rock mentioned above. No. 8, the stone bank that Stanley Gardiner mentions, is still persisting. On the whole the evidence would appear to be in favour of the view that these islets are undergoing slow erosion, rather than that they have been recently formed, and, therefore, that for some reason or other they were overlooked by Moresby when he made his original chart.

The next island of the series is Maradu; this is narrow and linear in shape and presents differing characters in its northern and southern parts. The northern part comprises about one-third of the whole island, and the formation of a bay on each side gives rise to an appearance as if the southern part had been displaced eastward or toward the lagoon. At the southern end of the island, where it faces Faidu Island, there is practically no beach at all; the island terminates in a small cliff about 2 ft. in height, which is thickly overhung

by bushes, so that anyone attempting to walk round this end of the island has to wade through water about a foot deep even at low tide. About 6 ft. from the end of the island the floor of the channel between it and Faidu drops steeply into deep water. The south-west corner of Maradu is composed of coral shingle, and here there is a small cliff about $2\frac{1}{2}$ ft. in height at the top of the shingle beach, along which the roots of overhanging bushes are exposed. It seems evident that at this point the island is being washed away. All along the west side of the southern portion of the island the beach at the time of my visit consisted of almost pure sand with a slight admixture of coral shingle, etc. On the northern side of the bay that forms the line of demarcation between the two parts of the island on its western side there is a wide expanse of coral conglomerate that runs out from the island towards the outer reef. This conglomerate is horizontally bedded, and is composed of masses of water-worn coral fragments that have become consolidated, and from its general character it seems that this formation is a part of the old reef flat that was originally laid down at some distance from the reef edge, as, for instance, in the shingle or boulder spits that run in from the boulder zone or reef crest, and subsequently became consolidated into a conglomerate rock; at the present day this rock is being steadily eroded away, and in places there are isolated blocks that are now completely surrounded by water and are much under-cut (Pl. VI, fig. 2). At the foot of this outcrop there are in sheltered places small collections of coral fragments that have been eroded out of the conglomerate. To the north of this point the beach slopes steeply upwards to the level of the island, and consists of sand and shingle with numerous outcrops of a fine coral conglomerate, gradually changing in character, as one proceeds northward, to a beach-sandstone; in one place near the north end there is a smooth expanse of what looked like beach-sandstone, but which on examination proved, instead of being hard, to be soft, like a thick clay. The north-west corner of the island is being gradually washed away; at this point there is a small cliff, about 2 ft. in height, along which the roots of trees, blocks of coral and coral shingle are exposed, and at one point, where originally an old lime-kiln for burning coral formerly stood, the cliff has fallen away, leaving only half the kiln still standing. On the lagoon side of the north end of the island a series of three sandspits run inwards towards the lagoon reef, and these are connected at their ends by a sandbank, which at low-water spring tides is only covered by about a foot of water, and which is continued to the north to connect with a similar sandbank running out from the south end of the island of Hankadu, the next island to the north. The lagoon beach of the northern end of the island consists entirely of sand, and slopes gradually up from the water-line. In this part of the island a well-marked line of pumice can be seen, running parallel to the foreshore, but about 10 to 15 ft. inside it. This line probably indicates that this amount has been added to this side of the island since the explosion of Krakatoa in 1883. It is interesting to note that this is almost the only part of the north end of the island that bears coco-nut palms, the western part being covered with a low scrub jungle, that closely resembles the vegetation on the islands of the eastern part of the atoll, especially Putali and the islands to the south of it. As one proceeds further to the south along the lagoon beach one finds outcrops of beach-sandstone, and this is especially the case where the land juts out towards the lagoon reef to form the south shore of the small bay, where the northern and southern parts of the island meet. Close to this bay a pit was dug in an attempt to find fresh water; in the topmost 4 ft. we encountered at first a layer of earth, mixed with roots of trees; then came a layer of white sand, below which

was a stratum in which the sand had become consolidated into a sandstone. Under the sandstone was a second layer of sand, and then came a mass of coral boulders, the old reef platform. It seems clear that this island is steadily being driven inwards across the reef platform and, moreover, that this process has been going on for some considerable time. The western side of the island is undoubtedly undergoing erosion, while the eastern side is to some extent eroded during the north-east monsoon, but during the south-west monsoon sand is piled up on the lagoon or leeside of the island, and this more than counterbalances the process of erosion.

The line of coral horses on the outer reef flat, to which I have referred above (*vide supra*, p. 71, and Pl. III, fig. 1), indicates, I think, the original line of the outer or seaward face of the island, and the small islands on the reef flat that lie in the same line as the " coral horses " may possibly also be parts of the original island, in which case the inward drift of the island would appear to have been greater in the southern than in the northern part of the island.

The next island, Hankadu, is separated from Maradu by a channel that contains deep water in the central part between the islands, but which shoals considerably both at its inner and outer ends. Towards the west it shoals to join the reef flat, while at its lagoon end there is, as I have already mentioned, a sandbar on the lagoon reef flat connecting the sand spits from the two islands. The floor of the deep part of the channel is plentifully overgrown with scattered colonies of stag's horn coral (*Acropora*), and in the shallower water on the west side were several small colonies of *Heliopora cœrulea*. According to Stanley Gardiner (1903, p. 418), at this point " there are traces of a former passage into the atoll lagoon in a less consolidation of both the seaward and lagoon edges of the reef, the latter being still very imperfect and the former having practically no boulder zone ". I cannot agree with this. I could detect no trace of any less consolidation in the outer reef, and the defect in the lagoon reef, which is certainly present at this point, I attribute to the detrimental effect on coral growth of the sand and silt that is at every rise of the tide swept off the outer reef flat, through the channel, on to and across the lagoon reef at this point.

The island of Hankadu is small and comma-shaped, its southern end running out in a curved, narrow spit. Lying to the west of this southern area in the concavity of the curve, but separated from it by a fairly deep channel, is a small unnamed islet that is completely destitute of vegetation, and consists merely of a line of coral-rock on its seaward face and a raised bank of coral shingle on its lagoon side. It is interesting to try and trace the history of this small island Hankadu and its associated islet. In Moresby's original chart there is no trace of any island in this situation, but at the time of Stanley Gardiner's visit in 1900 an island was present and is shown on the chart that he gives (1903, p. 415), while he remarks (*loc. cit.*, p. 418) that it " has a narrow rocky line ". The shape of the island, however, as given by him is very different from that of the present day, and there was apparently no trace of the accompanying islet. It seems probable that both Hankadu and the islets were originally part of the island to the north, now known as Abuhera, but shown in Moresby's and Stanley Gardiner's charts as Ru-jehey Hera or Ruehi-Hera, and that it first became separated off as a small island, as shown by Stanley Gardiner, and then since his visit has been still further eroded and split up into the small island and its attached islet that I found, while there has at the same time been an inward or lagoonward drift of the sand-spit at the south end of Hankadu. This island, or rather the mass

of coral rock that forms its west side, represents the northernmost extension of the line of coral horses and the small rocky islets that runs down the outer reef flat on the west side as far as Faidu and Gan Islands.

The next island, Abuhera or Ruehi-hera, appears to have originally been continuous with the island Hitadu to the north, and in Moresby's chart they are shown as parts of one island, the northern portion being called Hitadu and the southern Ru-jehey Hera. At the present day this island is completely separated from the islands to the north and south of it by channels, though from its southern end a sand-spit runs out into the channel towards Hankadu. Both in its structure and general appearance this island differs from the other islands of the western rim and much more closely resembles those of the eastern side. The island lies much nearer to the reef margin than the islands further south, so that the outer reef flat is in this part comparatively narrow and the island comes close to the boulder zone. At the southern end of its western side the island is built up of rounded and water-worn coral boulders, that form a raised ridge along the sea face, similar to the condition found in Putali on the east side of the atoll (Pl. IV, fig. 1), but conspicuously absent from the other islands on the west side to the south of this, though closely resembling the character of the small islets of the reef flat on the west of Faidu and Gan. The outer face of this boulder beach slopes steeply down to sea level. Inside this beach the rampart slopes down in a talus slope to the general level of the island, that is here covered with a dense scrub. Further north the boulder beach becomes replaced by a coarse shingle in the upper part of the beach, and shingle mixed with sand in the lower slopes, while outcrops of coral rock are met with. At the north end of the island two spits of coral boulders run outwards across the reef flat, exactly as they do on the east side of the atoll. The inner or lagoon side of the island is bordered by a beach composed entirely of sand, which has a steep slope that at the extreme south end of the island becomes almost vertical. Along the lower slopes of the beach at many points there is an outcrop of beach sandstone, showing the typical laminated structure, and beyond this there is a sharp drop of about 2 ft. The central portion of the island is depressed, though there is no " kuli " or central pool of water, such as one finds on the islands of the east side. The vegetation of the island consists almost entirely of a bush-scrub, with scattered coco-nut palms and Pandanus trees. The structure of the island clearly indicates that it has been built up on or just internal to the boulder zone, and that sand has drifted against the leeside of the raised beach ; the inward drift of the island has been comparatively slight in comparison with the amount of drift that has taken place in the islands of Hankadu, Maradu and Faidu to the south. The separation of this area of land from Hitadu appears to have been of recent occurrence ; even in 1900 no such separate island seems to have existed. Stanley Gardiner in his chart (1903, p. 415) gives no indication of any separation, though he remarks (*loc. cit.*, p. 418), " by Ruehi-Hera (the name given to the southern extremity of Hitadu Island) there were signs of an irruption of the sea across the land, but no definite gap was created ". Since 1900 this gap has become definitely established, and the detached area of land now forms the island Abuhera.

The last island to be considered on the west side is Hitadu. This is a long island, occupying the north-western horn of the crescent. I was only able to pay a single visit to this island and am, therefore, unable to give any very detailed account of it. The lagoon beach in the part that I saw consisted of sand and shells, but at the northern end this is replaced by coral boulders, and a narrow spit of the same material runs towards the south,

enclosing a large shallow area with a sandy bottom much overgrown with weed. Continuing the line of the spit are two small islands, both of which are built up of coarse coral shingle, with a certain amount of sand. The western side of the island consists in the main of a beach of coral boulders, with exposures of coral rock along its margin ; and for some distance in from the beach the island appears to be composed of weather-worn fragments of coral, on which a number of scattered bushes have obtained a foothold. Towards the northern end the coral-boulder beach is replaced for some distance by a sandy one, and then the boulders begin again, and the whole of the extreme northern end of the island is built up of these coral masses. Somewhere on the island there is a pool of fresh or nearly fresh water ; I did not see it myself, but the local inhabitants brought me a number of examples of a small fish of a species of *Barbus*, and several tadpoles, probably those of *Bufo melanostictus*, since this is also found to exist and breed in a small artificial pool that has been constructed on Maradu Island, and they informed me that they obtained them from a large pool on the island.

The northern part of the reef platform is almost destitute of islands. I have already mentioned the linear series of small islets that occur on the west side of Midu (*vide supra*, p. 73). The isolated part of the reef between the two northern entrances bears one small island, Bushy Island, and two sand-cays. The island is roughly shaped like a Greek *v*, and enclosed between the diverging horns is a pool of salt water that has been converted into a fish-trap, a wall of stones having been built up across the gap, so that the sea flows in as the tide rises, while on the ebb this area becomes cut off and thus any fish that have made their way in are trapped. This island seems to have increased in size to some extent since Moresby made his original survey, for he shows it as a sandbank with a few bushes, whereas at the present time it is covered with trees and jungle. The main area of the northern reef is destitute of islands, and I believe that the reason for this is that they have all been washed away.

To sum up the results of my survey of the islands, one must conclude that with the exception of the north-east part of Midu Island in the north-east horn of the atoll, which seems to be growing out, though it is being eroded away on its lagoon aspect, and is thus drifting across the reef flat in the opposite direction to most of the other islands, and possibly also with the exception of Hitadu at the north-west angle and Mulikadu on the south-east side, which appear to be more or less stationary, all the other islands are undergoing erosion on their seaward faces. In every case the presence of coral rock along the beach indicates that the upper layers of the beach are being removed, and the rocky substratum, which was originally part of the old reef flat before the fall of sea level raised it to its present height and caused the formation of land, is thus laid bare and is in its turn undergoing erosion. Erosion is further indicated by the presence of fallen trees or dead and dying bushes along the sea face, together with cliffing of the beach. The amount of erosion that has been so far achieved differs on the two sides of the atoll, and is considerably less on the north-east and east sides than on the south-west and west ; this is only what one would expect from the different strengths of the two monsoons. On the east side the islands for the most part have not yet been driven in beyond the extent of the boulder zone, though one island has completely disappeared. On this face of the atoll, with the exception of Midu and the northern part of Putali, which have doubtless been modified by human agency, the general type of vegetation on these boulder-zone islands is a low bush-scrub, with occasional palm-trees. On the western part of the rim,

and especially in the islands of Maradu, Hankadu and Abuhera, a greater degree of erosion has taken place and now the islands lie well inside the boulder zone, often with a wide stretch of water between them. On the boulder-zone itself are a few small islets, as we have already seen (*vide supra*, p. 81). As regards these latter, Stanley Gardiner (1903, p. 419) has attempted to explain their presence as a new formation ; he remarks, " Considering the whole formation, I am driven to the perhaps rather lame conclusion that the physical conditions in the S.W. of the atoll differ from those in other parts sufficiently to have in the first place produced a broad reef flat, largely by the washing away of the land, which loss is now being repaired by the formation of a fresh series of islands along the boulder zone of the reef ". I think that Stanley Gardiner was inclined to lay too much stress on the absence of any indication on these small islets of the boulder zone in Moresby's chart. Throughout the whole of this south-west part of the atoll there is conclusive evidence that the islands are being steadily driven inwards across the reef flat, and traces of their original western boundary can still be seen in the shape of blocks of hard coral breccia, the so-called " coral-horses ", in a linear series just inside the present boulder zone, the last of the series to the north being at the present time gradually laid bare by the erosion of the small islet of the south-west side of Hankadu. It seems clear to me that the islets to the west of Faidu and Maradu are equally the last remaining traces of the original western extension of these islands that, as in other islands on the boulder zone, at one time possessed a sea beach composed of a base of coral rock, surmounted by a rampart of coral boulders ; parts of this original sea beach still remain, having been sufficiently firm and dense to resist erosion, though breaches occurred at intervals, and the softer and less resistant sand and sandstone of the island were washed away, leaving these traces still *in situ*, though gradually disappearing.

The vegetation of the islands on the western side of the atoll is in most of the islands much more dense than in the islands on the east, but here, too, in those islands that still maintain their original position in or near the boulder zone, we find that the greater part of the area, and especially the outer part of the island, is covered with a low bush-scrub, exactly comparable to that seen in the islands on the boulder zone of the east side.

One other point that seems worthy of consideration is the different character of the shingle and boulder spits that are found crossing the outer part of the reef between the islands and the boulder zone. In certain areas these run inwards from the boulder zone towards, but not reaching the island beaches, whereas in others the spits appear to run out from the islands towards, but not actually reaching the boulder zone. This difference I attribute to the degree to which erosion and the inward drift of the islands have taken place, and I regard the two conditions as successive phases in the process of erosion. At the commencement of erosion of an island, which typically consists of an outer rocky rampart and an inner sand flat, the sandy area is driven lagoon-wards and a line of separation between it and the rock rampart is established. In the next stage the island, now composed for the most part of sand, is still further driven lagoon-wards, and the rocky rampart becomes breached and eroded, coral boulders being set free from the rock, and these are driven inwards to form spits running islandwards from the line of coral horses on or near the original boulder zone. With further erosion the coral horses become gradually broken down and ultimately disappear, while the boulder spits are still further driven inwards and now reach as far as the island beach, against which they become piled, and eventually may form a new rocky rampart. If this be so then the island of Putali

on the eastern side and the northern end of the island of Abuhera on the western, though actually not so far removed from the present boulder zone as the islands Maradu and Faihu on the south-western side, represent a more advanced stage in erosion ; and this is further indicated by the complete absence of any coral horses on the reef between them and the reef crest. At first sight this may appear to be unlikely, since the distance between the reef crest and the islands Maradu and Faihu is far greater than between the reef crest and Putali or Abuhera ; but it must be borne in mind that the more rapid erosion may be due to a less consolidated condition in the original reef at the points where Putali and Abuhera now stand, and a greater consolidation opposite Maradu and Faidu ; and this is what one would expect, since at the south-west point of the atoll the waves of the south-west monsoon will be felt to a greater extent, and will therefore give rise to a condition that is more favourable to the growth of nullipores and the consequent hardness of the reef face.

THE LAGOON REEF.

Just as the islands on the reef platform exhibit considerable differences on the two sides of the atoll, east and west, so there is a marked difference between the lagoon reef of the two sides. Commencing at the north-east corner of the lagoon, the inner reef flat is here over a mile wide and a large portion of it dries completely at low-water spring tides. Along the inner side of the northern reef platform the edge of the reef is well defined, but at the north-east corner there is a break in its continuity, and a second line of dead coral reef that at low tide shows well above the water level, running in a north-south direction, lies across the mouth of the gap between Midu and Heratera Islands. To some extent obstructing this gap in the reef and extending further inshore are numerous isolated patches of coral, that rise almost vertically from the sandy floor of the lagoon to within a foot or two of the surface, leaving between them a network of small channels that have a depth of 3 to 5 fathoms of water. The whole of this north-east corner of the lagoon thus forms an area of what is technically termed " foul ground ". Stanley Gardiner (1903, p. 318), in his account of the lagoon of this atoll, describes at this point of the lagoon a continuous inner or lagoon reef, and between it and a second inshore reef an elongate area of deep water or " velu ", with a depth of 5 fathoms. A comparison of this account and the condition as I found it in 1934 seems to show that the inner lagoon reef at this point has been broken down, and all that remains of it is a scattered " jungle " of coral heads that rise from 3 to 5 fathoms with passages between the pinnacles. I have already pointed out that erosion is going on in the bay on the outer reef between Midu and Putali, and that with the rise of the tide quantities of sand and mud are swept through the channel between the two islands and over the reef flat on the west side ; and it seems to me that at the present time the destructive effect of the mud and sand, combined in all probability with the ravages of boring organisms, has caused a breaking up of the lagoon reef at this point. Further to the south, where the lagoon reef becomes continuous, the bulk of the reef is composed of masses of dead coral, which have become more or less cemented together by smaller fragments and by an admixture of sand and of the remains of other calcareous organisms. For the greater part of its length the upper surface is covered by several inches to a foot of water even at low-water spring tides, but in places occasional colonies of living coral growing on the surface of the reef are (Pl. VII, fig. 1) exposed for a short period, and large masses of dead coral project for a foot or two above the surface. These

large masses of dead coral are eroded and water-worn, but they appear to be still standing *in situ*, and in many cases are far too large to have been thrown up on the reef by such waves as even a gale from the south-west could raise inside the lagoon. The only conclusion to which one can come is that we have here evidence of a relative alteration in the sea- and land-level, and that they are the remains of the old lagoon reef that has not yet been completely destroyed. If this be so, then it is clear that the lagoon reef in this part of the atoll has been stationary for a very long period of time. In places the surface of the reef is composed of round or oval masses of Astræaceæ, the upper surface of many of which has been killed off and is now composed of dead coral, often hollowed out in " pot-holes " ; scattered over the surface of the reef, either in these pot-holes or on the dead coral, are a number of colonies of live coral, conspicuous among which are oval or rounded colonies of the " corymbose " type of madrepore (*Acropora*) (Pl. VII, fig. 2), together with small colonies of *Pocillopora*, *Coeloria*, *Seriatopora* and various species of Astræaceæ, while examples of *Fungia*, in both the free and sessile stages, are not uncommon ; among the coral small patches of a yellow Alcyonarian are not uncommon. Taken as a whole, however, the coral growth on the reef is not luxuriant. The inner margin of the reef slopes downwards towards the lagoon for a few feet, and then drops steeply down to a depth of 8 to 10 fathoms. This inner wall of the reef can be seen on a calm day to be built up of large masses of solid coral, and the surface is thickly studded with growing colonies of madrepore, while in places, commencing about 3 ft. below the surface, are large colonies of a fan-shaped madrepore coral of a pale yellow colour ; when viewed from the surface this latter growth closely resembles that of a gigantic cup-coral, but actually it is composed of very stout broad plates, expanded more or less horizontally, with a few short branches growing out from the edges. At a still greater depth, and commencing usually at about 1 fathom, and so sufficiently deep to be unaffected by the damaging force of the lagoon waves, are large colonies of a dark brown, slender stag's-horn madrepore. These branching corals are usually inhabited by crabs and brightly-coloured fish, while the masses of Astræaceæ are studded with numerous Serpulid worms of all hues, red, orange and blue being the prevailing colours. A few Crinoids of a brown colour and an occasional large brown Holothurian can be seen attached to the surface, while in the grooves between the rounded masses of solid coral are examples of *Tridacna*, whose mantle, when the valves are open, is easily recognizable as a vivid patch of colour, usually blue or purple.

The reef flat at the north-east corner is over a mile wide and for the most part the water covering it is shallow ; the level slopes downwards gradually as one proceeds out from the beach, until near the reef there is a depth of 3 to 5 fathoms, but inshore at low-water spring tides extensive areas are laid bare. This flat is composed of a mixture of sand and lamellibranch shells, and large areas are covered with a grass-like plant (*Cymodocea* ?), but the greater part is bare of weed, and the sand is thrown up into numerous mounds by burrowing organisms. In one or two places towards the lagoon edge of the flat masses of dead coral still stand, showing where coral-heads originally flourished. On this part of the flat I only succeeded in obtaining one Sipunculid and a few Polychæt worms, together with a few specimens of a species of burrowing crab of the genus *Macrophthalmus*. In the channel connecting the inner and outer reef flats between Midu and Heratera examples of a black Holothurian, *Holothuria atra* (?), and a species of *Synapta* are common, while the sand and shingle is thrown up into mounds by burrowing Holothurians, white in colour with pale brown mottlings, that usually lay at a depth of about

6 in. below the surface. Further south on the west side of Putali the inner reef flat is considerably narrower and is only some 600–700 yards across ; considerable stretches dry at low water, but as one proceeds southwards the amount laid bare by the tide diminishes. Along this part of the reef flat the floor consists of sand mixed with small fragments of coral ; in the shallow water towards the island beach there are occasional small masses and boulders of dead coral, with patches of *Halimeda*, but towards the lagoon reef patches of coral become of more frequent occurrence and are of larger size, and, instead of being completely dead, living coral is in places maintaining a somewhat precarious existence. Near the reef itself the water has a depth of about 3 fathoms, and there is a well-defined boat channel, that is, however, considerably obstructed by large masses of growing coral.

Stanley Gardiner (1903, p. 321) states that Holothurians and Sipunculids, two of the most important sand-triturating organisms, were singularly scarce in Addu atoll, both on the reef and in the lagoon. This, however, was not my experience. I have already mentioned that in the channel between Midu and Putali both *Holothuria* and *Synapta* are common, and the same is true of the adjoining part of the outer reef flat. On the inner reef flat to the west of Putali at least three species of Holothurians are common ; just on the shore side of the lagoon reef they are particularly common, especially a species that either is, or closely resembles *Holothuria atra* ; a fairly conservative estimate of the frequency of occurrence would be one in every square yard of reef surface. Further inshore in the shallower water opposite Putali there was one in about every two square yards, and these examples were for the most part small, measuring only 6 to 8 in. in length, and though black in colour, were rendered much less conspicuous by a thick dusting of sand over them.

In the south-east corner of the lagoon the line of the lagoon reef becomes irregular and is broken in one or two places, while inshore, between it and the islands, we again find an area of " foul ground ", the surface of the reef flat being covered with a maze of growing coral. Opposite Mulikadu and the boulder ridge connecting it with Kaluhera the water on the reef-flat shoals gradually, and the floor consists almost entirely of a coarse sand and shingle, while thickets of stag's horn madrepore grow up from its surface. It would seem that at this point the inner lagoon reef is being destroyed, and fragments of coral and sand derived from the lagoon reef are being swept across the reef flat and, as we have seen (*vide supra*, p. 79), during storms from the north-west are flung up on the island. It is of some interest to note that in such situations, where there is reason to suspect considerable movement of sand along the bottom, stag's horn madrepore appears to be the only type of coral that can maintain its existence ; as I shall mention later (*vide infra*, p. 91), on the west side of the atoll in the channels between the islands and on the margins of the sand bars that nearly completely obstruct their lagoon ends we get similar thickets of stag's horn coral ; presumably the explanation of this is to be found in the liability of other species of coral, that have a less elevated type of growth, to be sooner or later smothered by the sand, and so killed off. Even in these thickets of stag's horn coral the supporting trunks are dead and overgrown by a filamentous alga, and only the terminal branches and twigs are still living and healthy.

On the south-west and west side of the lagoon the reef shows several points of difference from the reef on the east. In the first place, the reef itself lies much nearer to the island beaches than on the east, this, of course, being due to the degree to which these islands of the western side have been driven across the reef flat and have, in

consequence, approached the inner or lagoon reef. In this segment of the atoll the inner reef flat is only some 200 yards wide and the water over it is shallow; opposite Gan Island there is a small boat channel between the reef and the island that communicates with the lagoon by one or two narrow openings through the reef, but further to the west, off Maradu Island, there is no definite boat channel, and the depth of water between the reef and the island is only a few feet. On this western side, and especially on the inner or lagoon part of the reef flat, the growth of coral is much more prolific than on the east. Stanley Gardiner (1903, p. 319) remarks that the coral growth in Addu atoll was more luxuriant than anything that he had seen elsewhere, and certainly this portion of the reef would seem fully to justify his description. The reef flat opposite Maradu Island is wide, and its upper surface, which is well exposed at low-water spring tides, appears to consist of four zones. The inner zone nearest the lagoon slopes slightly downwards to the edge of the reef; it consists of a foundation of dead coral rock upon which are growing numerous, closely-set, rounded or oval colonies of madrepore (*Acropora*), each colony measuring about 1 ft. in diameter. These colonies are very similar to the colonies that I have already mentioned as growing on the upper aspect of the lagoon reef on the east side, but here they are vastly more numerous. The actual inner margin of this zone is cut up by numerous small gullies and fissures, that run somewhat irregularly over the surface and remind one of the fissure zone of the outer reef (Pl. VIII, fig. 1). Immediately outside this zone is a second one, about 5 yards wide, in which the surface of the reef flat is almost level and resembles a road that has been made of very coarse cobble-stones; the whole of the surface of this part of the reef consists of closely-set, small colonies of Astræids, and in every case the central part of the colony, which usually measures some 9 in. across, is dead and eroded, only the perimeter of the colony consisting of living coral. Scattered over this zone are small water-worn masses of dead coral, and the number of these increases as one proceeds northwards toward the part of the reef that lies opposite the extreme north point of Maradu Island, where they constitute a third zone along the shore side of the reef. The fissured character of the reef margin and the increasing prevalence of these dead coral boulders, that suggest a boulder zone in miniature, as one proceeds northwards along the reef, is probably correlated with the increased effect of the swell that during the south-west monsoon sets in to the lagoon through the southern openings and then sweeps in a north-westerly direction across the lagoon, the force and height of the breakers increasing from south to north along the reef. Proceeding still further outwards towards the islands the next zone slopes downwards away from the lagoon and is covered at low-water spring tides by 6 in. to a foot of water; here the floor of the flat is composed of coral rock with a small admixture of sand; the coral growth is particularly luxuriant, and forms a wide belt that spreads inwards towards the islands. So profuse is the growth of coral that it is quite impossible to describe it in detail, but the photograph of it (Pl. VIII, fig. 2) shows this clearly. Patches of stag's horn coral, for the most part brown in colour with white tips to the branches, abound, and here, too, the lower parts of the main stems are usually dead and overgrown with a filamentous alga. Numerous colonies of Astræaceæ, as well as *Pocillopora*, *Seriatopora* and patches of leathery Alcyonarians, are scattered over the reef flat, while giant Actinians of the genus *Discosoma* and numerous Holothurians, of several species, are to be seen. Further inshore in the last zone this coral growth becomes patchy in character, and simultaneously the floor of the reef flat changes to sand, and finally the coral growth ceases entirely.

Opposite Maradu and in one or two other places along this side of the lagoon the inner margin of the lagoon reef does not drop steeply to the floor of the lagoon, as it does on the east side, but slopes down to a terrace that runs along the reef, and it is only on the inner side of this terrace that the reef drops sharply to the lagoon floor. Opposite Maradu this terrace has a width of about 30 yards and lies at a depth of 2 or 3 fathoms. So far as I could see, the terrace consists in the main of patches of live coral with a sandy floor between. Darwin (1889, p. 140) has called attention to the presence of such ledges on the lagoon side of the reef in certain atolls, and he explains them by the supposition that the atoll has at one time or another subsided too rapidly for the upward growth of the coral to counteract the downward movement, and that, in consequence, the old rim has been killed off and a new rim has grown up, leaving the terrace to denote the original level of the old rim. Without denying the possibility of such an explanation in certain cases, it seems impossible to apply it to the present instance because, as this terrace is only present in one section of the lagoon rim, we should have to suppose that there had been unequal subsidence in the different parts of the same atoll. The true explanation of the terrace is, I think, to be found in its situation on the south-west side of the lagoon ; during the growth of any reef a talus slope is gradually formed along its foot, and on the south-west side of the lagoon its formation will have been materially assisted by the destructive action of waves in this section of the reef, to which I have already alluded, as well as by deposition of sand and debris that is swept over from the outer reef platform. I have already (*vide supra*, p. 81 *et seq.*) shown that a considerable amount of erosion is, and has been, going on in the islands of the reef flat on this western side of the atoll, and the bulk of the products of this erosion appears to be swept through the channel between Hankadu and Abuhera Islands, though some, and possibly a considerable amount, passes between Maradu and Hankadu. With the single exception of the somewhat tortuous channel between Midu and Heratera, at the north-east corner of the lagoon, there is no channel on the east side through which there is a continuous flow of water from the outer to the inner reef flat and so to the lagoon at all states of the tide, whereas on the south-west side this is going on through all the channels ; at the same time the water on the outer reef flat is heated up to a considerable extent during low tide, and as the tide rises, this is swept through the channels on to and beyond the inner reef flat. To this action I attribute the wide interval in the lagoon reef that occurs opposite the gap between Hankadu and Abuhera Islands ; here the floor of the lagoon shoals gradually upwards to the sand-bar that connects the two islands on their lagoon sides, and the bottom consists entirely of sand dotted over with clumps of stag's horn coral, which, as I have already mentioned, appears to be the only type of coral that can maintain its existence on a sandy bottom, such as that which we are considering. Some of the sand is doubtless deposited on the inner reef flat, and it is to this that I attribute the almost complete disappearance of the boat-channel in this region ; but much of it is doubtless swept on into the lagoon, where it will serve to augment the talus slope, and in all probability has caused the appearance of shoal patches, one of which is shown on Moresby's chart opposite the middle of Maradu Island.

In the north-west corner of the lagoon the reef is fairly continuous, and shuts off an area of deep water near the village that is situated at the north end of Hitadu. It seems likely that in this area the growth of coral is extending. Moresby, in his original chart, shows the north-west area as open, with a depth of water of 5 to 10 fathoms ; but at the

time that Stanley Gardiner visited the atoll there seems to have been some considerable change, for he remarks (1903, p. 319) that " the upper part is a fairly clear basin, covered on the bottom with muddy sand. Towards its mouth, where it opens into the lagoon, these coral heads stud the whole surface, arising perpendicularly—perhaps overhanging at the top—from 10 fathoms or even deeper. Many of the knobs have grown together, so that a passage to the head of the bay is at the present time difficult for a vessel of any size, if not impossible ". At the time of my visit, so far as I could discover, there was only a single passage, marked by poles stuck in the bottom, through which a dhow could pass ; Certainly all dhows, when approaching this village at the head of the island, made use of this channel. The whole of the rest of the mouth of the bay is occluded by reefs.

THE LAGOON.

Moresby, in his original chart, shows a maximum depth of water in the lagoon of 39 fathoms in the north-east part ; he also records the presence of six shoal patches ; of these, three are situated in a triangle near the centre of the lagoon, one lies close to the reef on the east side of the south-east entrance, one near the lagoon reef on the west side, opposite Maradu Island, and finally a shoal patch in the north of the lagoon close to the isolated part of the reef between the two northern entrances.

In 1900 a series of soundings were taken by Forster Cooper, and the results that he obtained have been summarized by Stanley Gardiner as follows : " Making every allowance for the possibility that the soundings may have been too low—of which, nevertheless, there was no indication—the greatest depth obtained by my companion was 32 fathoms, where 36 fathoms ought to have been found. Where 39 fathoms are charted, only 31 fathoms were obtained. Isolated soundings may mean nothing on account of difficulty of fixation—in this atoll intensified by considerable changes in the land. Eliminating all but the most careful observations—many having been taken when dredging—23 are left, all of which show a decrease in depth of from 1 to 8 fathoms, the general reduction being 2 or 3 fathoms." From this evidence Stanley Gardiner concluded that the lagoon was silting up.

The average depth of water in the lagoon, excluding the shoal areas to the north-east and north-west, is, according to Moresby's chart, some 24·4 fathoms ; Forster Cooper's soundings give an average depth of only 21·5 fathoms. But the average depth, as shown by both Forster Cooper's soundings and ours together works out at 24·5 fathoms, which is almost exactly the same as that obtained by Moresby a hundred years earlier, so that on the whole it would appear probable that conditions in the lagoon are more or less stationary, though it is possible that under the influence of storms and the consequent increase in the currents and waves in the lagoon there may be a certain amount of movement of sediment from one part to another, resulting in an apparent increase of depth in some areas and a corresponding decrease in others.

Acting on the assumption that there has been little or no change in the depths, I have taken the chart published by the Admiralty and that given by Stanley Gardiner and have superposed these, and from the depths as given I have drawn the contour lines corresponding to the 20- and 30-fathom depths. The result is given in Text-fig. 1. From this it becomes quite evident that it is incorrect to speak of the lagoon having a flat floor. The distance of the 20-fathom contour from the edge of the lagoon reef varies enormously in different parts of the lagoon circumference ; this is particularly evident in the

northwest area, where there is an area of " foul ground " thickly dotted over with coral heads, and again in the eastern part of the lagoon, opposite the middle and south end of Putali Island. In this latter area the inward sweep of the 20-fathom contour line is in all probability correlated with the erosion that, as we have seen, is going on along the southern end of Midu-Huludu Island and the northern end of Putali, and that has formed the wide bay on the seaward side of these two islands ; the sand and silt derived from this erosion is being swept, under the influence of the north-east monsoon, through the gap between these islands, and is then carried to the south-west, and is probably being deposited on the lagoon floor in the area immediately to the west of Putali Island. The 30-fathom contour line clearly indicates that there are two deep areas in the lagoon, in each of which water of a depth of 36 fathoms has been found. In the south-west half of the lagoon this deep area is comparatively small, but in the north-east area the deep portion is much larger and extends close up to the lagoon reef in the region where the anchorage is shown on the Admiralty Chart, 34 fathoms having been obtained close to the lagoon reef. The central part of the lagoon, where a group of three shoals are indicated on the chart, intervenes between these two deep regions, and it seems probable that this shallower belt, with the deep areas on each side of it, is correlated with the currents of water that enter the lagoon through the two sets of entrance channels on the north and south sides of the atoll.

According to Stanley Gardiner (1903, p. 319), " the bottom of the lagoon was found by my companion, Mr. Forster Cooper, to be covered with rubble and sand, one small patch of mud only existing at 27 fathoms to the head of the north-east horn. . . . Sedentary, and indeed all other organisms were on this class of bottom singularly scarce." This comparative scarcity of the fauna of the lagoon floor has been noticed and commented on by almost every observer who has studied these and similar atolls ; and it is difficult to understand why coral does not and apparently cannot grow up from the floor of such a lagoon. During our visit a haul of the large grab was made in the north-east corner of the lagoon and a good sample of the bottom was obtained. This consisted of a fine cream-coloured mud that possessed a distinct odour of sulphuretted hydrogen, and a subsequent chemical examination showed that this gas was present to the extent of at least 4·9 mgrm. per litre of the occluded water, after this had been aspirated off from the sample. The mere action of aspirating off the water must have reduced the amount of gas originally present, so that it is justifiable to conclude that at least 5 mgrm. of the gas per litre were present *in situ*. The presence of this gas in such quantity may well prove to be distinctly adverse to coral growth or to the existence of other forms of animal life ; but this is a problem that must await further researches.

BIBLIOGRAPHY.

Agassiz, A. 1903. The Coral Reefs of the Maldives. Bull. Mus. Comp. Zool. Harvard, XXIX.

Coral Reef Committee of the Royal Society. 1904. The Atoll of Funafuti.

Darwin, C. 1889. The Structure and Distribution of Coral Reefs (Third Edition). London : John Murray.

—— 1897. A Naturalist's Voyage round the World (1897 edition). London : John Murray.

Farquharson, W. I. 1936. John Murray Expedition, Scientific Reports, I, No. 2, Topography.

Gardiner, J. Stanley. 1903. The Fauna and Geography of the Maldive and Laccadive Archipelagos, I. (University Press, Cambridge.)

—— 1906. *Op. cit.*, II.

Murray, Sir J. 1913. The Ocean. Home University Library of Modern Knowledge. London.

Oldham, C. F. 1895. Topography of the Arabian Sea in the Neighbourhood of the Laccadives ; (ii) The Physical Features of Some of the Islands. Journ. Asiatic Soc. Bengal, LXIV, part 2.

DESCRIPTION OF PLATE I.

FIG. 1.—The buttress and fissure zone on the N.E. side.

FIG. 2.—The outer reef flat and the S.E. part of Midu-Huludu Island.

FIG. 1.

FIG. 2.

[*Adlard & Son, Ltd., Impr.*

DESCRIPTION OF PLATE II.

FIG. 1.—Marine erosion on the north-east side of Addu Atoll, between Huludu and Putali.
FIG. 2.—The channel between Huludu and Putali Islands.
FIG. 3.—The boulder zone on the south-west side.

FIG. 1.

FIG. 2.

FIG. 3.

[*Adlard & Son, Ltd., Impr.*

DESCRIPTION OF PLATE III.

Fig. 1.—" Coral horses " on the western outer reef flat.
Fig. 2.—The north-east part of Putali Island.

FIG. 1.

FIG. 2.

[*Adlard & Son, Ltd., Impr.*

DESCRIPTION OF PLATE IV.

FIG. 1.—The inner face of the seaward rampart, Putali Island.
FIG. 2.—The lagoon beach of Putali Island.
FIG. 3.—Putali Island. Outcrop of sandstone on the lagoon beach.

FIG. 1.

FIG. 3.

FIG. 2.

[*Adlard & Son, Ltd., Impr.*

DESCRIPTION OF PLATE V.

FIG. 1.—One of the fresh-water pools on Putali Island.

FIG. 2.—A brackish-water lake : the northernmost of the outer series of Putali Island.

FIG. 1.

FIG. 2.

[*Adlard & Son, Ltd., Impr.*

DESCRIPTION OF PLATE VI.

FIG. 1.—The reef flat and outer beach of Mulikadu Island.

FIG. 2.—The coral breccia exposure on the west side of Abuhera.

FIG. 1.

FIG. 2.

[*Adlard & Son, Ltd., Impr.*

DESCRIPTION OF PLATE VII.

FIG. 1.—The lagoon reef on the north-east side.

FIG. 2.—A near view of coral colonies on the north-east reef.

FIG. 1.

FIG. 2.

[*Adlard & Son, Ltd., Impr.*

DESCRIPTION OF PLATE VIII.

FIG. 1.—The inner margin of the lagoon reef on the south-west side.
FIG. 2.—Coral on the inner reef flat on the south-west side.

FIG. 1.

FIG. 2.

[*Adlard & Son, Ltd., Impr.*